2017

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Clayton McDowell
University of Wollongong, claytonm@uow.edu.au

Georgios Kokogiannakis
University of Wollongong, gkg@uow.edu.au

Laia Ledo Gomis
University of Wollongong, laia@uow.edu.au

Paul Cooper
University of Wollongong, pcooper@uow.edu.au

Abstract

Energy poverty is a prevalent issue in Australia and other countries across the globe especially for people with a low income. This paper seeks to investigate the relationship of energy consumption and indoor air temperatures and is separated into 3 sections; a comparison of actual electricity consumption to energy benchmarks provided by the Australian Energy Regulator, monitoring results of living room air temperature for the winter of 2015, and an analysis of living room air temperatures versus electricity consumption. The results of a comparison of electricity consumption of 119 low income elderly peoples (60+) dwellings to that of the energy benchmarks found that over 75% of the Independent Living Units consumed less electricity than the benchmark values with some households consuming less than half of the benchmarked electricity values. The analysis of living room air temperatures found that approximately 10 % of the dwellings experienced temperatures below 16°C for over 65% of the total hours for the winter of 2015 with some as high as 95% of the total hours. The results of this paper highlight a need to investigate this cohort separate from the average Australian cohort as their energy consumption practices can vary greatly and impact their living room air temperature.

Keywords

low, income, homes, australia, indoor, air, temperatures, energy, relationship, bills, between

Disciplines

Engineering | Science and Technology Studies

Publication Details

McDowell, C., Kokogiannakis, G., Gomis, L. L. & Cooper, P. (2017). Relationship Between Indoor Air Temperatures And Energy Bills For Low Income Homes In Australia. Energy Procedia, 121 174-181.

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 121 (2017) 174–181

Energy Procedia

www.elsevier.com/locate/procedia

International Conference on Improving Residential Energy Efficiency, IREE 2017

Relationship Between Indoor Air Temperatures And Energy Bills For Low Income Homes In Australia

Clayton McDowell[a,*], Georgios Kokogianakis[a], Laia Ledo Gomis[a], Paul Cooper[a]

[a]*Sustainable Buildings Research Centre (SBRC), Faculty of Engineering and Information Sciences, University of Wollongong , Northfields Avenue, Wollongong 2522, Australia*

Abstract

Energy poverty is a prevalent issue in Australia and other countries across the globe especially for people with a low income. This paper seeks to investigate the relationship of energy consumption and indoor air temperatures and is separated into 3 sections; a comparison of actual electricity consumption to energy benchmarks provided by the Australian Energy Regulator, monitoring results of living room air temperature for the winter of 2015, and an analysis of living room air temperatures versus electricity consumption. The results of a comparison of electricity consumption of 119 low income elderly peoples (60+) dwellings to that of the energy benchmarks found that over 75% of the Independent Living Units consumed less electricity than the benchmark values with some households consuming less than half of the benchmarked electricity values. The analysis of living room air temperatures found that approximately 10 % of the dwellings experienced temperatures below 16°C for over 65% of the total hours for the winter of 2015 with some as high as 95% of the total hours. The results of this paper highlight a need to investigate this cohort separate from the average Australian cohort as their energy consumption practices can vary greatly and impact their living room air temperature.

Peer-review under responsibility of the scientific committee of the International Conference on Improving Residential Energy Efficiency.

Keywords: energy consumption; low income; residential; indoor environment

* Corresponding author.
E-mail address: claytonm@uow.edu.au

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Peer-review under responsibility of the scientific committee of the International Conference on Improving Residential Energy Efficiency.
10.1016/j.egypro.2017.08.015

1. Introduction

Since the 1980's the concept of fuel or energy poverty as it is commonly referred to in Australia and how to define and measure it has been discussed and debated [1,2]. Until 2013 the UK defined fuel poverty as when 10% or more of a households income would need to be spent to provide a comfortable and safe temperature level within the dwelling which was defined as 21°C for the living room and 18°C for other occupied rooms [3]. Following the Hills review [2], the UK has since revised this definition to the Low Income High Cost (LIHC) which has since sparked further debate [4]. In Australia a formal definition of fuel poverty has not been given, however, a recent paper provided five definitions with the estimated percentage of households living in energy poverty varying from 2% to 14% depending on the definition [5]. A key finding of this paper was that Aged pensioners have a higher likelihood of experiencing energy poverty along with those who live in duel fuel households (mains or bottled gas) [5].

Although many measures and definitions of energy poverty exclude the need to be able to heat the home to a comfortable and healthy level, these effects need to be considered when making policy decisions. The study presented in this paper was conducted as part of the Energy + Illawarra project which sought to improve the energy efficiency of the houses of 800 elderly (aged 60 years or older), low income people whilst maintaining or improving their thermal comfort. This was achieved through a multidisciplinary approach involving social marketers, human geographers and engineers. Within the Energy + Illawarra project, a building characterization and retrofit program was undertaken that targeted 200 dwellings. Energy consumption data was collected for each of these dwellings and 170 received air temperature monitoring of their primary living room.

Similar studies that have been conducted in the past include the HEEP study which involved 397 dwelling across New Zealand and installed 774 living room temperature sensors, 380 bedroom temperature sensors, 37 external temperatures and 30 other room temperatures across the cohort. This study discovered fuel poverty issues with those of lower income experiencing lower mean living room temperatures and expending a larger proportion of their income on winter heating [6,7].

The aim of this paper is to investigate the relationship of energy consumption and indoor air temperatures for 119 low income households from the Illawarra region in Australia that were part of the Energy + Illawarra project. The paper is separated into 3 sections; a comparison of actual electricity consumption to energy benchmarks provided by the Australian Energy Regulator, monitoring results of living room air temperature for the winter of 2015, and an analysis of living room air temperatures versus electricity consumption.

Nomenclature

AER	Australian Energy Regulator
CDD	Cooling Degree Days
HDD	Heating Degree Days
Own	Owner occupied dwelling
ILU	Independent living unit located within retirement villages
n	Household sample size

2. Methodology

2.1. Energy benchmarking

Gas and electricity billing data was sourced from local energy distributors for the period of March 2013 to March 2016. For the Illawarra region in Australia and for the majority of Australia this data is collected via manual meter reads that occur at three monthly intervals. This places meter read dates at any period throughout the year and thus inhibits the direct separation of the data into seasons. This issue is referred to as 'billing lag' [8]. To mitigate the effects of this lag on results and to enable a direct comparison to the energy benchmarks to be made, the methodology applied in the ACEL Allen Consulting report was employed [8]. This method calculates the mid-date of the billing period (three months in our case) and assigns the season of this date to this billing period.

To obtain the Australian Energy Regulator (AER) benchmarked energy consumption, it is required to know the postcode, number of occupants, presence of mains gas connection and presence of swimming pool for each dwelling. This data was collected during a building characterization audit as a subtask of the Energy + Illawarra project, which were then processed to derive the seasonal and annual benchmark of the total kWh and kWh/day for electricity consumption [9]. It should be noted that gas consumption benchmarks for each post code were not publicly available for this study and therefore our study focusses only on electricity consumption.

For the Illawarra region in Australia, the benchmarked values separated the study area into two climate zones [8]. These two zones will be used as the basis of the following discussion and their respective post codes and descriptions can be found below in Table 1. To further illustrate the weather conditions of these two climate zones, three weather stations were selected and the climatic conditions for 2013 to 2015 are displayed in Table 2.

Table 1. Benchmark climate zones [8]

Climate zone	Postcode range	Description
1	2500 – 2534	Warm temperate climate
2	2539 – 2579	Mild temperate climate

Table 2. Climatic conditions for Albion Park, Nowra and Moss Vale for 2013, 2014 and 2015.

Climate Zone	Location	Year	CDD	HDD	Mean Annual Temperature (°C)	Number of Days with			
						Max T>30°C	Min T<14°C	Max T > 35°C	Min T< 2°C
1	Albion Park	2013	94.4	995.8	17.0	13	248	3	5
		2014	63.7	934.3	17.1	10	224	0	10
		2015	92.2	1008	16.9	16	223	6	9
	Nowra	2013	121.4	1100.4	16.8	22	259	4	0
		2014	97.3	1045.7	17.1	29	229	2	1
		2015	115.1	1181.9	16.8	26	236	9	0
2	Moss Vale	2013	72.8	2066	13.4	20	316	6	40
		2014	59. 5	2054.4	13.6	14	306	2	40
		2015	49.2	2165.1	13.1	9	309	1	59

The data collection and analysis used to generate the benchmark employed a series of controls to avoid demographic bias and to ensure the sample remained representative of the Australian population. One such control included limiting the sample to include no more than 5% of people of 65 years or older [8]. In contrast the sample collected in this project exclusively targeted a population of low-income people aged 60 years and older. Thus some variation is expected between the benchmark and this project but the analysis below provides an evaluation of how this sample of low-income people aged 60 and above differs from the broader Australian population.

Dwellings that use wood fuel have been included in the analysis below, however dwellings with solar photovoltaic have not been included. This action was taken because the electricity data provided by the local energy distributor does not identify whether a dwelling with PV solar installed is ‘gross’ or ‘net’ metered and thus it is not possible to determine actual household electricity consumption per se. For the purpose of this paper only 119 dwellings were included as these met the above conditions and had both electricity consumption data and living room air temperature data.

In summary the process followed for the analysis of the electricity consumption benchmarks was as follows:

- Gather historical electricity data from the local energy distributor.
- Process electricity data into seasons by calculating the mid-date of the billing period and assign the season of this date to the relevant electricity bill.
- Average the seasonal electricity values for all three available years.
- Obtain seasonal electricity benchmark data from the Energy Made Easy benchmarking tool [9].
- Filter out dwellings that have PV solar installed and dwellings without living room air temperature data (living room air temperatures were monitored for 170 houses out of the 200 that received energy retrofits).

- Calculate the variation between the electricity data and benchmarks by subtracting the benchmark values from the historic electricity data.

2.2. Living room air temperatures

Indoor air temperature was logged in the main living area of 170 dwellings via a pair of 'iButton' DS1922L temperature sensors. The two sensors were installed side-by-side on an internal wall, in a position that avoided direct heating and cooling from devices and direct sunlight throughout the day, and at a height of approximately 1.1m above floor level. Logging at half-hourly intervals with 0.5°C resolution provided a data capture memory capacity of 11 months. The sensors were installed in the dwellings during a building characterization audit from February to May 2015 with the data retrieved during January and February 2016, thus available data covered the period of May 2015 through to January 2016. For the purpose of this paper only data from winter 2015 (1st of June to 31st of August) and dwellings that had available electricity data were included giving 119 dwellings.

3. Results and discussion

3.1. Energy benchmarking

An analysis of the annual average daily electricity consumption and percentage of difference from the benchmarked values was performed for Climate zones 1 and 2 using energy data from March 2013 to March 2016; results are shown in Figure 1. The box plots have been separated to cover dwellings with and without gas. It was found that the majority of dwellings consumed less electricity than the benchmarked values with exception of dwellings without gas in Climate zone 2 which had an even spread above and below the benchmarked values.

This analysis was further explored by separating the ILUs (i.e. houses within retirement villages) from the owner occupied dwellings, and is presented in Figure 2. For clarity of display of Figures 2 and 3, one outlier has been removed from the owner occupied dwellings in Climate zone 1 which consumed over 300% more electricity than the benchmark. This analysis revealed that over 75% of the ILU's consumed less electricity than the benchmark values for both climate zones, with a median of 24.7% and 35.2% below the benchmark values for climate zone 1 and 2 respectively. Note the sample size for the ILU dwellings in Climate zone 2 was only nine and thus the outputs are used for gaining insights only for the electricity bills of the specific cohort rather than drawing generalized conclusions from it. In contrast to the ILU's, the owner occupied dwellings were found to have similar electricity consumption to that of the benchmark with a median of 6.7% and 2.4% below the benchmark values for Climate zones 1 and 2 respectively, and with some dwellings consuming electricity twice that of the benchmarked values.

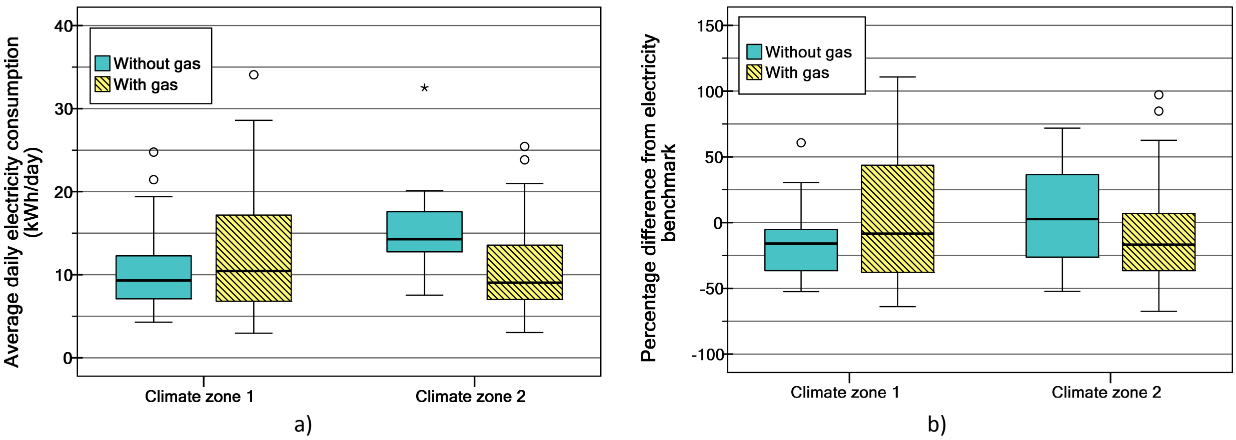

Fig. 1. Annual electricity consumption with and without gas (a) daily average (b) percentage difference from benchmark (sample size n = 44, 23, 19, 33). Benchmark data was sourced from [9].

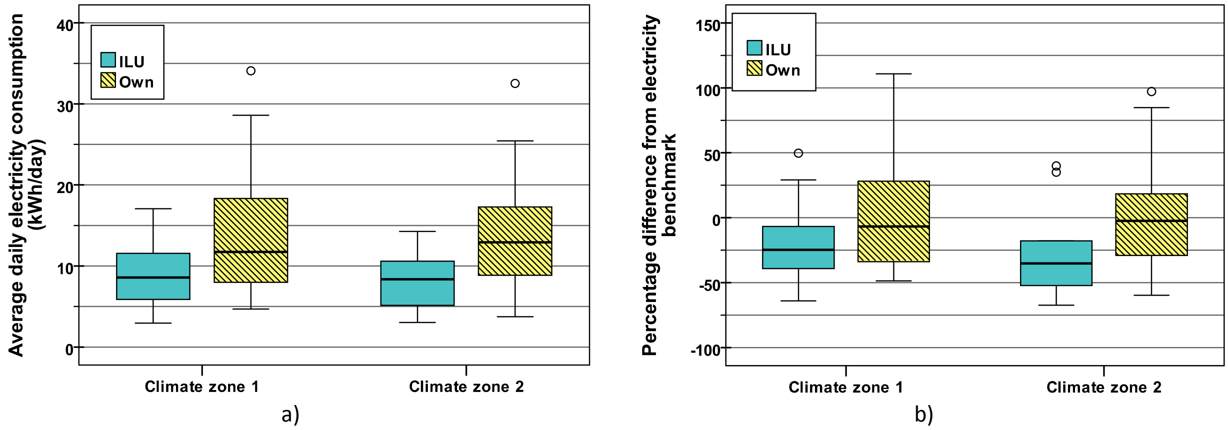

Fig. 2. Electricity consumption in winter (a) daily average (b) percentage difference from benchmark (sample size n = 36, 30, 9, 43). Benchmark data was sourced from [9].

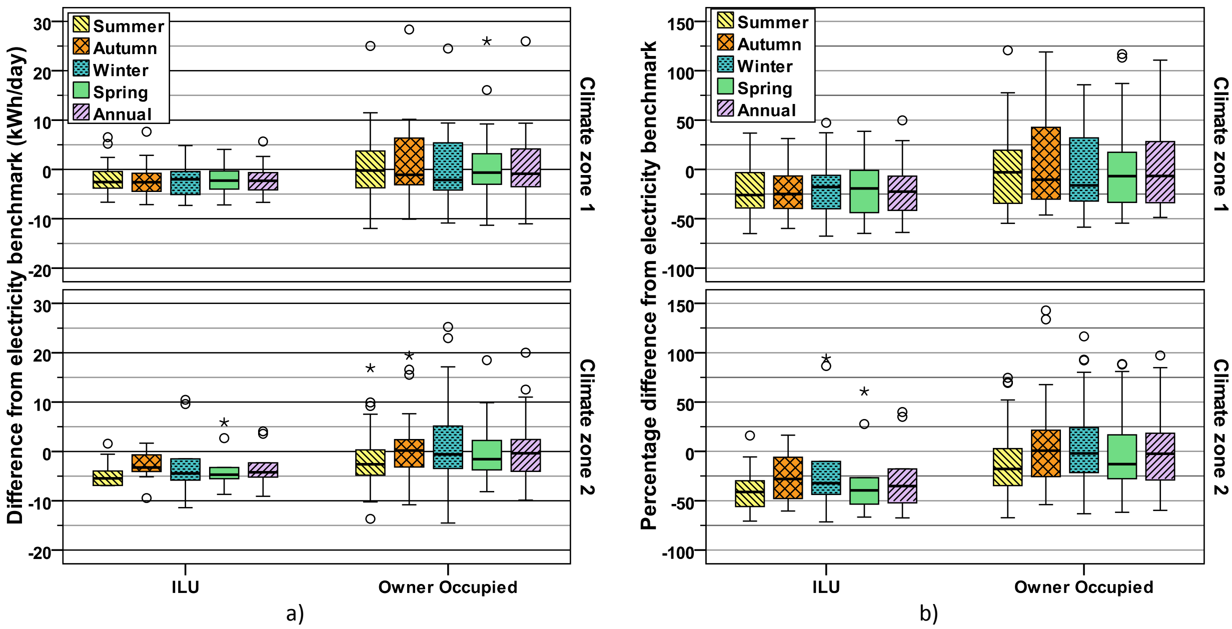

Fig. 3. Seasonal electiricty consumption (a) daily average (b) percentage difference from benchmark (sample size n = 36, 30, 9, 43). Benchmark data was sourced from [9].

A comparison was also made between the seasonal average daily electricity consumption and the benchmarked values for both climate zones and is presented in Figure 3. In comparison to the electricity benchmarks it was observed that the electricity consumption for the owner occupied dwellings was on average higher in summer and autumn for Climate zone 1 and autumn and winter for Climate zone 2. These initial findings suggest that owner occupied dwellings in Climate zone 1 may benefit from retrofits for summer cooling and dwellings in Climate zone 2 for winter warming.

3.2. Living room air temperatures

An analysis of the all of the available winter living room air temperature data was undertaken for Climate zones 1 and 2; results are shown in Figure 4 (a). It was found that for both the ILUs and the owner occupied dwellings, the median living room air temperature was 17.6°C and approximately 16.7°C in Climate zones 1 and 2 respectively. The World Health Organization (WHO) recommends that a healthy range for indoor temperatures is between 18 and 21°C, with a minimum temperature of 20°C for those who are young or elderly [10]. Indoor air temperatures outside a range of 16°C to 28°C are likely to cause significant thermal discomfort, which in turn is often linked to health problems, in particular for the elderly [11]. Thus this analysis was further explored by plotting the total number of winter hours below 16°C; results are shown in Figure 4 (b). It was found that there was a large amount of variation in percentage of hours below 16°C for both climate zones and ownership types with some dwellings experiencing over 90% of winter hours below 16°C. For both climate zones, the median values for the percentage of hours below 16°C in ILU's were found to be less than that of the owner occupied dwellings (Figure. 4 (b)).

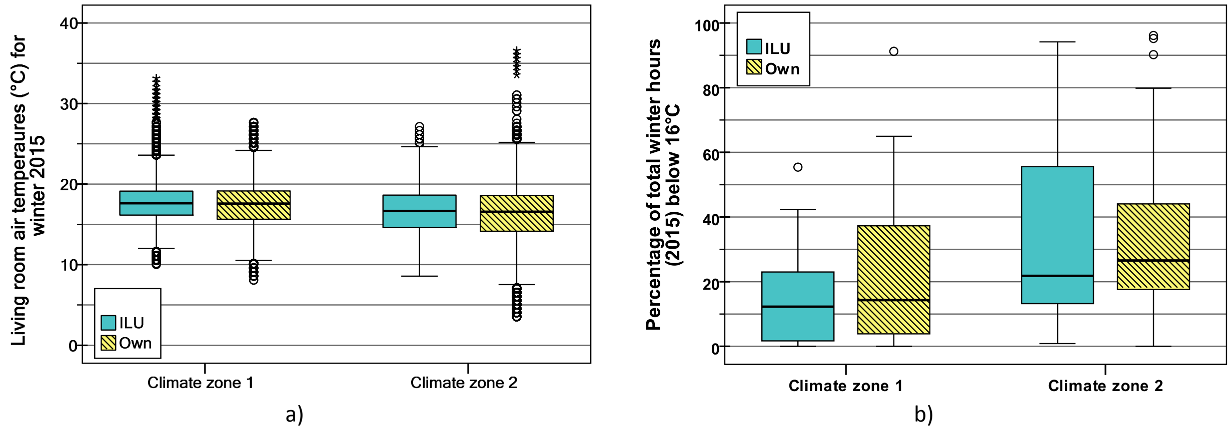

Fig. 4. Living room air temperatures for winter 2015 (a) all available data (b) percentage of hours below 16°C (sample size n = 36, 30, 9, 43).

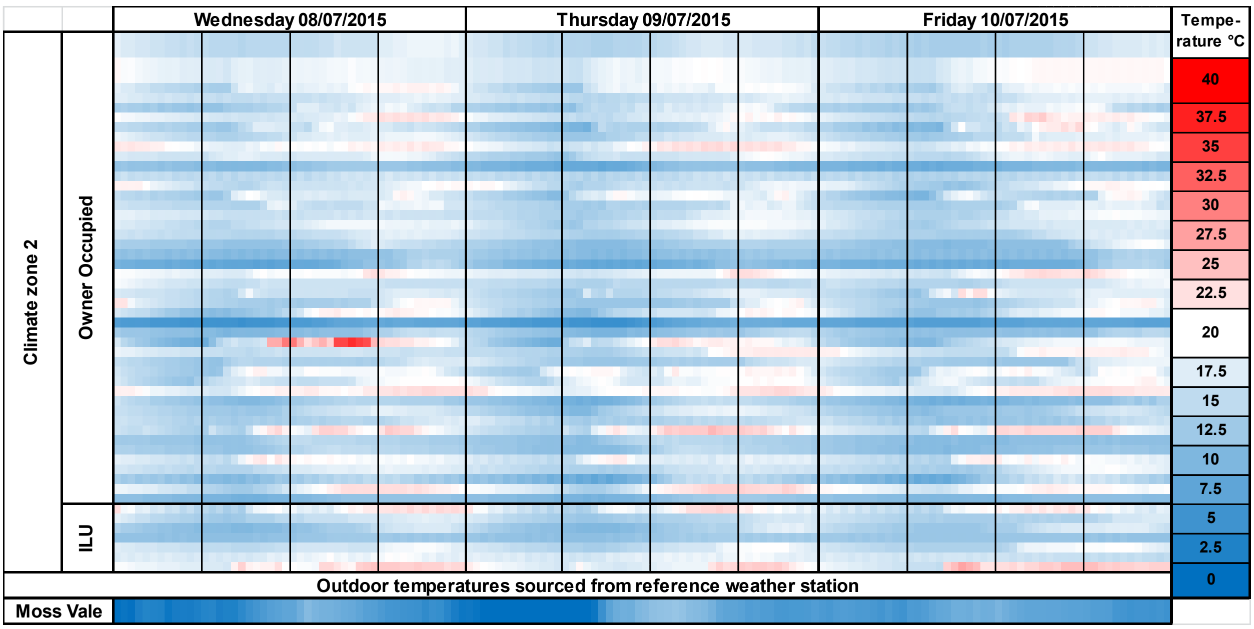

Fig. 5. Heat map of dwellings between Wednesday the 8th and Friday the 10th of July 2015 for Climate zone 2

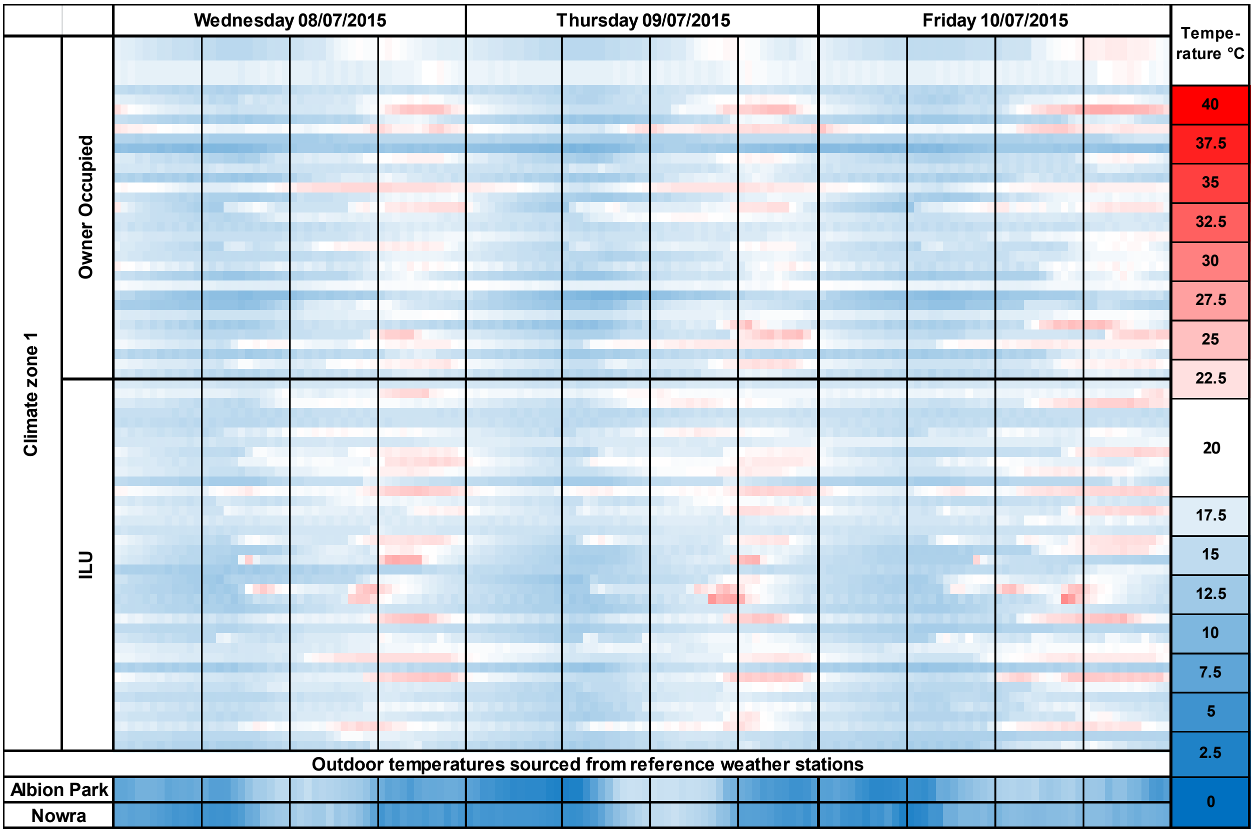

Fig. 6. Heat map of dwellings between Wednesday the 8th and Friday the 10th of July 2015 for Climate zone 1

To provide an example of some user practices two heat maps were produced for three cold days during winter 2015 with each row representing a dwelling and three weather stations provided for reference to outdoor climatic conditions; results are shown in Figures 5 and 6. For this analysis, 20°C was selected to represent a neutral white with a red gradient to 40°C and a blue to 0°C. It can be observed that for the majority of dwellings, peak living room air temperatures are experienced after 9:00 pm suggesting the use of heating or practices generating internal loads large enough to warm the dwelling. It is observed that some dwellings are heated to over 30°C where others are observed to employ no heating and remain below 10°C for the whole duration.

3.3. Trends between indoor air temperature and energy consumption

An analysis of energy consumption versus percentage of total winter hours below 16°C for 2015 was undertaken for both ILU and owner occupied dwellings; results are shown in Figure 7. From the results in Figure 7, there were no clear findings in that dwellings with higher energy consumption did not necessarily experience a lower amount of hours below 16°C, nor those with high number of hours below 16°C did not necessarily consume less electricity than others. However these initial findings do highlight some dwellings that use a considerably large amount of electricity whilst remaining comfortable and others that spend a considerable amount of time below 16°C whilst using very little electricity. Figure 6 shows also the existence of well-performing houses that demonstrate low energy use and at the same time low number of hours below 16°C. All of these findings warrant further research to understand the occupant behaviors and building characteristics that may influence these results and methods for reducing energy consumption whilst improving thermal comfort.

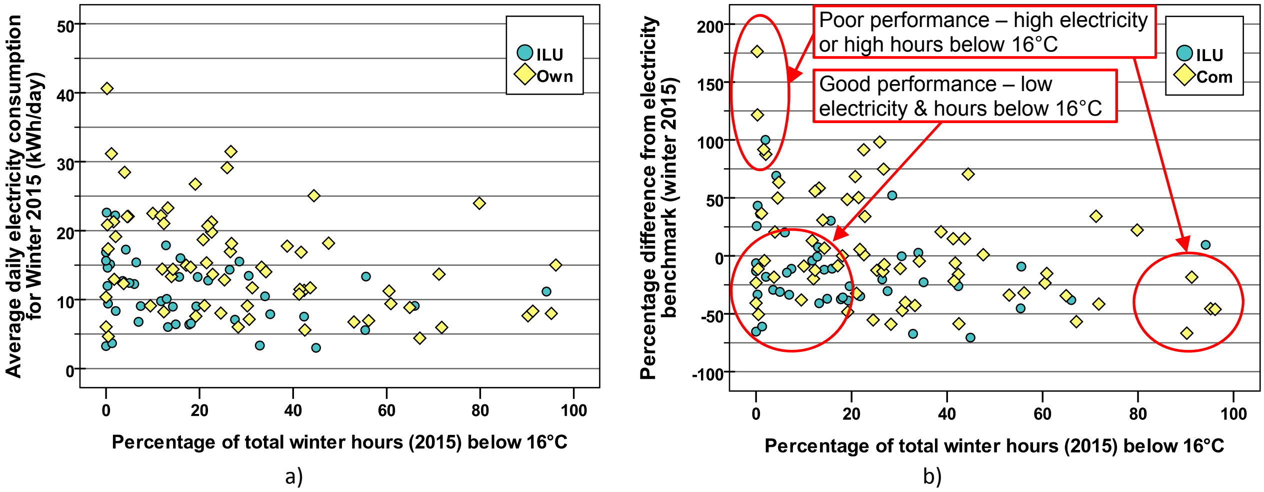

Fig. 7. Electricity consumption against percentage of winter hours below 16°C (sample size ILU = 44, Own = 68) (a) average daily consumption (b) percentage difference from benchmarks [9].

4. Conclusion and Recommendations

Our initial findings suggest that although the ILUs were found to have median energy consumption values lower than the owner occupied dwellings, they had slightly higher median living room air temperatures. The reasons for such observations could vary and include: occupant practices, type of heating devices, building characteristics or the sample size. It was highlighted that some households appear to live in extremely cold conditions with living room air temperatures below 16°C for over 90% of the winter hours. This can also be observed in the heat map (shown in Section 3.2) which provides some high level findings of the indoor conditions in low income households in winter, which could be attributed onto how occupants were heating their dwellings and the quality of building envelope or the overall building design. The next stages of this study will see living room air temperatures compared with hourly energy consumption as well as building characteristics, heating types, and occupant practices.

5. Acknowledgements

We wish to thank all our EE3A consortium partners. This activity received funding from the Australian Government, Department of Industry and Science Low Income Energy Efficiency Program. The views expressed herein are not necessarily the views of the Commonwealth of Australia, and the Commonwealth does not accept responsibility for any information or advice contained herein.

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